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N INITIAL ANALYSIS OF THE DATA FROM THE
OLAR ORBITING GEOPHYSICAL (POGS) SATELLITE

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ABSTRACT

The POGS (Polar Orbiting Geophysical Satellite) was launched in 1990 to measure the geomagnetic field. POGS data from selected magnetically quiet days was selected and quality checked and deleted where thought to be erroneous. A time and position correction was applied. The resulting data was fit to a degree 13 spherical harmonic model. Evaluation of the quality of the data indicates that it is sufficient for definition of the low degree (say, less than 8) portion of the geomagnetic field. Further correction of the data time and position may improve this quality.

INTRODUCTION

POGS (Polar Orbiting Geophysical Satellite), a project of the Naval Oceanographic Office (NOO), was launched by an Atlas E rocket from Vandenberg Air Force base in April of 1990 into a circular polar orbit of approximately 800 km at an inclination of 89.5°. The satellite was equipped with a vector fluxgate magnetometer mounted on an eight foot earth-pointing boom. Each axis of the instrument has a range of ± 65535 nT with a resolution of 2 nT. No absolute instrument was carried to correct for instrument drift, and the vector attitude information was insufficient for attitude corrections of the accuracy required for solid Earth geophysical applications. The instrument drift rate was supposed to be no greater than 50 nT/yr (Acuna, personal communication) and the attitude accuracy is thought to be about 0.5° to 1.0°. POGS is stabilized by the gravity gradient method and because of deployment problems, was injected into orbit upside down. This caused problems with the solar panels (i.e., power) and telemetry antenna. Although the latter problem has currently been worked around by reconfiguring the transmission and reception pattern of the ground station tracking, the data used in this study suffers from large gaps. A more severe problem concerns the magnetometer clock. The accuracy of its correspondence to GMT is in error by as much as 5.5 seconds. Correcting this problem is discussed in the following section.

DATA SELECTION AND CORRECTION

The preliminary POGS data set was provided to us by John Quinn of the NOO. From the provided data, passes were chosen during days which were relatively magnetically quiet, as determined from preliminary Kp values. For this initial study, no further attempt was made to eliminate magnetically disturbed data. The selected days, the three hourly Kp index, and the number of observations selected are shown in Table 1. Figure 1 shows the geographic distribution of the resulting data.

The method used for correction of data time with UT was not properly functioning during 1990 but was made operable in January of 1991. Since the presently considered data are from 1990, the assigned time can be in error by several seconds. Rough estimates of the required time corrections were supplied along with the initial data by NOO. These corrections were determined by NOO using a trial and error procedure in which, for selected days, spherical harmonic models were derived using a suite of time offsets. The offset resulting in the lowest residuals (i.e., best fit) to the data was considered to be the time correction needed. The process was complicated by the fact that the answer was bi-modal, i.e. there were two times giving a minimum in the residuals. The selected time was taken to be midway between the two minima.

The resulting corrections estimate the magnetometer - ephemeris time offset in seconds for thirteen days between Julian day 152 and 257. Time offsets ranged from 5.5 to -0.6 seconds for these days. Coefficients for a quadratic function were computed from the time correction information and were used to determine the appropriate time shift for each observation. Figure 2 shows the corrections and the fitted quadratic function.

Satellite positions at the revised data times were then computed and appended to the observations. This was accomplished by calculating X, Y, and Z velocities from the ephemeris data and using these together with the time correction offsets to compute corrected positions. The entire procedure is very ad hoc.

EVALUATION

Residual POGS data were plotted for each of the quiet days after removing the GSFC(8/91) model as shown in Figure 3. This model is fit to the POGS data itself, as described in a later section. The quality of the data is suspect owing to the long-wavelength features (about 21000 km wavelength) which are approximately equal to one half orbit. It is presently assumed that this feature is a function of the satellite - ephemeris time offset since the time correction given by NOO was preliminary.

DATA CLEANUP

Poor attitude control and lack of an absolute instrument alone preclude the use of the POGS satellite vector magnetometer data in solid Earth geophysical applications. However, scalar (B) data computed from the observed vector measurements may be of use since they are independent of orientation. In order to ensure quality, the scalar data were assessed with respect to a field model and the accepted residuals were then assessed with respect to a B-spline function. This evaluation was performed via a program, called FILTER, originally designed for DMSP satellite processing (Ridgway et al., 1989; Langel et al., 1990).

Specifically, FILTER evaluated the data in 86400 second (one day) pieces, hence each quiet day was processed independently. Table 1 shows the date, the Kp Three-Hourly indices, and the number of measurements for each of the 13 quiet days used. The first task was to compute scalar residuals (ΔB) from a field model and then flag as outliers points with residual magnitudes exceeding 1000 nT. Flagged measurements were excluded from further analysis. The field model used was the United States Geological Survey (USGS) 1990 IGRF candidate main field model, including the secular variation estimation for 1990-1995. This model is of degree 10 in its internal field spherical harmonic expansion and of degree 8 in its secular variation terms.

The second task was to fit a cubic B-spline, with internal knots every 100 seconds, to the accepted ΔB. The times of the earliest and latest accepted data point served as external knot positions. The B-spline scaling factors were determined via an unweighted least-squares estimator. Those measurements whose B-spline residual magnitude was found to be greater than twice the rms of the B-spline fit were flagged and excluded from further analysis. The number of measurements remaining for each day after the evaluation are shown in Table 2.

COMPARISON WITH FIELD MODELS

As a preliminary method of assessing the data quality, it was compared with the candidate IGRF models for 1990. These models are summarized in Table 3. The statistics to each model are given in Table 4.

A FIRST MODEL FIT TO THE POGS DATA

Since the goal is to determine the validity of the POGS satellite magnetometer data in main field modeling, it is logical to calculate the best fit model with the culled data. A degree 13 internal spherical harmonic expansion was determined by the POGS B data. This model is denoted as GSFC(8/91) and is given in Table 5. The USGS 1990 IGRF candidate model was used as a starting model and its secular variation

terms used to reduce the data to 1990. The mean radius of the Earth's is taken to be 6371.2 km with a flattening factor of 1/298.25. The model was determined by a weighted least-squares estimator, which was iterated 4 times. The scalar data was assigned a uniform uncertainty of 25 nT.

The residual mean and sigma with respect to GSFC(8/91) for the data from each of the 13 quiet days as well as collectively are listed in Table 2. The weighted residual variance suggests a calibration factor of 1.4 for the GSFC(8/91) covariance matrix, which would increase the data uncertainty from 25 to 29.6 nT in accordance with the overall residual sigma (see Table 2).

Figure 4 shows a plot of the quantity R_n, defined as the total mean square over the Earth's surface of the magnetic field intensity produced by harmonics of the n'th degree. R_n is given by

$$R_n = (n+1) \sum_{m=0}^{n} [(g_n^m)^2 + (h_n^m)^2].$$

For comparison, the plot also shows R_n from the degree 23 MGST(10/81) model (Langel and Estes, 1982) based on Magsat data. At degrees where the amplitude of R_n from GSFC(8/91) exceeds that from MGST(10/81) it is likely that GSFC(8/91) is contaminated by some noise source. This is particularly evident at and above degree 8 and, to a lesser extent, degree 6.

Table 6 shows the coefficient by coefficient differences between GSFC(8/91) and IGRF 1990 (IAGA, 1991). Note that this is a different field model than that used in the data cleanup process.

CONCLUSIONS

This study must be regarded as very preliminary if for no other reason than the uncertainty in the assigned times, and hence positions, of the data. Nevertheless it gives indication that the POGS data is of acceptable quality for modeling the low degree (n < 9, at least) terms in the geomagnetic field.

Possible drift in instrument calibration will always be a question for this data. Fluxgate magnetometers are not absolute instruments and are known to drift with time. For example, there was an apparent, though small, drift in the Magsat vector data (Langel et al., 1981) which was detected and adjusted for by comparison with an absolute scalar instrument. POGS has no such absolute instrument. Similarly, no absolute instrument was present on the DE-2 spacecraft. Langel et al. (1988) describe a comparison of the DE-2 data with co-temporaneous surface data to attempt to detect any shifts, biases, etc. in the DE-2 data. Very small adjustments were made and an apparently reasonable field model produced. When final time corrections are available, and when sufficient co-temporaneous surface data are available, such an assessment of the POGS data would be useful.

Even if no apparent drift is detected, its possible presence will always be an open question. There is simply no way to be certain regarding its presence or absence. This implies a, hopefully small, degree of uncertainty in temporal change models incorporating the POGS data. An upper bound for this uncertainty is not yet available.

A follow-on POGS mission is under consideration in combination with the DMSP series of spacecraft. In particular, a fluxgate magnetometer is planned to be located at the end of a 5 m boom on a future DMSP mission. Data from such a configuration would be greatly enhanced over POGS I and over prefious DMSP data. Such data would benefit from the excellent DMSP attitude determination and would undoubtedly be free from the timing and telemetry problems experienced with POGS I. The boom should effectively eliminate the spacecraft field noise experienced on prior DMSP missions.

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TABLE 1: QUIET DAYS SELECTED AND NUMBER OF DATA AVAILABLE

Day	Date	Kp Three-Hourly Indices 1	2	3	4	5	6	7	8	Number of Points	Local Time of Ascending Node
173	6/22	2	2+	1+	1	1+	1+	1-	2-	1135	14.2
174	6/23	2-	1	1+	2+	3-	2+	1+	1-	5154	14.1
179	6/28	2	2	3	2+	2-	2-	1	1	1513	13.8
180	6/29	1-	3	3-	2-	2+	2-	2+	1	5457	13.7
192	7/11	2-	2	2	1+	1+	1	3	1+	3743	12.9
208	7/27	1	2+	2	3-	2-	2+	3	2+	3157	11.9
213	8/1	1	2-	3+	2+	5	4+	5	5-	1626	11.5
214	8/2	3+	3-	3-	2-	2-	1	1+	3-	5238	11.5
218	8/6	2-	2	2	2-	1+	3-	3+	2+	4590	11.2
219	8/7	2+	2-	1+	2-	2	2-	2	2+	1464	11.1
222	8/10	1-	1	1	2-	2-	1+	2+	3-	3823	10.9
223	8/11	3+	2-	2+	2-	2+	2	1+	2+	1229	10.9
237	8/25	1+	1+	1+	1-	1+	2	2+	3-	6060	9.9

Table 2. Statistics of POGS data for each selected day versus GSFC(8/91)

Day	Date	Points	Residual Mean	Residual Sigma
173	6/22	1050	15.8	26.9
174	6/23	4885	14.4	33.2
179	6/28	1494	13.7	20.9
180	6/29	5178	11.1	27.8
192	7/11	3584	-4.7	34.6
208	7/27	2977	-5.5	30.7
213	8/1	1487	-23.9	34.5
214	8/2	4850	-12.8	28.3
218	8/6	4162	-6.2	20.5
219	8/7	1369	-4.5	19.2
222	8/10	3608	-6.9	19.7
223	8/11	1180	-2.6	24.9
237	8/25	5825	4.7	26.7
	Total	41649	-0.03	29.6

TABLE 3: CANDIDATE IGRF MODELS

Model Designation	Submitting Institute	Submitting Authors
BN	BGS/NOO	Barraclough and Quinn
G	GSFC	Langel et al.
GD	GSFC	Langel et al.
IZ	IZMIRAN	Bondar and Golovkov
US	USGS	Peddie

BGS/NOO: Joint submission by the British Geological Survey, Edinburgh Scotland, and the U.S. Naval Oceanographic Office, Stennis Space Center, MS., USA

GSFC: Goddard Space Flight Center, Greenbelt Md., USA

IZMIRAN: Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Moscow, USSR.

USGS: United States Geological Survey, Denver Co., USA.

Table 4. POGS data statistics versus candidate IGRF models

Model	Residual Mean	Residual RMS	Residual Sigma
G *	-51.4	65.5	40.6
GD *	-43.9	61.4	42.9
BN	-56.5	74.6	48.8
US	-47.9	64.1	42.5
IZ	-56.6	73.1	46.2

Table 5

Model: Pogs initial model from 13 quiet days

n	m	g	h
1	0	-29732.	
1	1	-1882.6	5393.6
2	0	-2124.1	
2	1	3052.6	-2286.0
2	2	1613.5	-343.17
3	0	1295.9	
3	1	-2221.5	-261.75
3	2	1192.2	286.25
3	3	863.54	-525.26
4	0	938.38	
4	1	782.01	248.60
4	2	363.49	-254.83
4	3	-426.55	85.732
4	4	53.966	-336.80
5	0	-203.42	
5	1	345.32	28.661
5	2	279.02	167.21
5	3	-135.33	-99.153
5	4	-119.45	-71.898
5	5	-44.257	210.21
6	0	59.702	
6	1	63.632	-16.344
6	2	40.806	83.504
6	3	-171.01	68.487
6	4	25.349	-38.039
6	5	5.6900	-24.026
6	6	-21.388	-25.912
7	0	73.926	
7	1	-65.039	-65.096
7	2	-15.263	-32.189
7	3	35.672	-12.021
7	4	-26.480	24.046
7	5	8.6854	-16.569
7	6	4.2912	-22.969
7	7	-24.238	16.353
8	0	25.946	
8	1	8.4681	8.7647
8	2	5.4103	-22.122
8	3	-12.582	4.1999
8	4	-17.001	-28.496
8	5	11.502	26.665
8	6	-14.164	28.189
8	7	0.94233	-6.9296
8	8	-2.5681	-19.926
9	0	5.0048	
9	1	8.4399	-25.900
9	2	10.699	17.633
9	3	-17.029	12.985
9	4	21.721	-7.0848
9	5	-6.8009	4.1828
9	6	-0.12736	10.397
9	7	16.902	-0.66389
9	8	-1.2858	-9.2348
9	9	-4.3810	-4.3605
10	0	-3.2767	
10	1	-6.1020	2.6794
10	2	-2.8326	0.69506
10	3	-2.7908	6.0484
10	4	0.23734	8.9498
10	5	1.1050	-11.083
10	6	7.2231	-7.7805
10	7	2.0458	-7.2489
10	8	3.5325	4.9069
10	9	7.8287	-7.7555
10	10	18.144	-12.714
11	0	3.0878	
11	1	-0.81645	4.3495
11	2	-5.1585	-0.26190
11	3	3.4480	-0.46565E-01
11	4	-5.2364	-2.0834
11	5	0.18076	-3.4512
11	6	-1.4335	-0.93881
11	7	-2.5095	0.57468
11	8	2.0516	0.56725
11	9	0.71271	-0.90374
11	10	6.7736	2.2292
11	11	-2.6881	6.8421
12	0	-1.1630	
12	1	1.4596	0.49037
12	2	0.51666	-1.7491
12	3	-0.36257	1.6342
12	4	-0.34273	-2.4540
12	5	1.9562	2.7968
12	6	-1.8491	2.3450
12	7	-0.12947	1.4810
12	8	1.4825	0.27023E-01
12	9	-1.7773	3.3708
12	10	-3.3694	2.0547
12	11	3.4512	0.79832E-01
12	12	8.5397	4.4010
13	0	-0.28335E-01	
13	1	-0.13988	-1.7881
13	2	2.5303	0.84801
13	3	-1.5340	-0.32415
13	4	2.5018	-0.27769
13	5	1.2043	1.2130
13	6	-0.91605	0.11857
13	7	2.1314	-0.35440
13	8	-1.6141	-0.63449
13	9	-2.8117	0.12723
13	10	-4.7228	-1.5790
13	11	1.2354	-3.7474
13	12	8.6169	-1.6486
13	13	6.0685	-0.22078

Table 6

DIFFERENCE GSFC(8/91)t - IGRF90

n	m	g	h	$\dot{g}$	$\dot{h}$
1	0	48.4100	0.0000	1.9792	0.0000
1	1	-38.0100	-6.8600	0.4316	0.0712
2	0	13.8100	0.0000	-0.0821	0.0000
2	1	-9.2300	-4.3400	0.6035	-1.2195
2	2	3.7800	3.0300	1.0289	-1.2108
3	0	-18.5800	0.0000	0.6711	0.0000
3	1	20.1900	24.5000	-0.3323	-0.4210
3	2	-7.5700	-6.2700	-0.0619	0.4235
3	3	11.4600	-47.5300	0.8633	0.5554
4	0	-3.8700	0.0000	0.5191	0.0000
4	1	-1.2800	0.9200	0.3882	0.4405
4	2	0.1300	-0.4700	-0.9819	0.1827
4	3	-1.2700	-11.0300	-0.5448	0.9028
4	4	1.3400	-10.6200	0.5354	0.3785
5	0	8.0300	0.0000	-0.6309	0.0000
5	1	-9.5100	-16.1700	0.1377	0.1195
5	2	4.2100	11.5300	-0.3685	0.5390
5	3	-8.2200	23.4500	-0.8843	-0.4491
5	4	9.5800	0.2300	0.0665	0.3401
5	5	-3.9600	9.3300	0.6835	-0.4084
6	0	1.3100	0.0000	0.7131	0.0000
6	1	2.0600	-6.2200	-0.8179	-0.2464
6	2	-1.3600	-5.7300	0.1885	0.3475
6	3	3.5100	3.7100	0.6879	0.0038
6	4	-3.0400	1.4800	-0.8281	-0.1188
6	5	-5.7100	-2.7900	-0.1272	0.5478
6	6	9.2600	-25.8500	0.8416	-0.2244
7	0	-3.5600	0.0000	0.4107	0.0000
7	1	0.1900	12.0800	0.5068	0.3837
7	2	-0.7100	-4.7000	0.3072	-0.1912
7	3	-2.5500	-4.5900	0.3733	0.2277
7	4	-7.9400	4.5700	0.4112	-0.4794
7	5	-2.7400	-5.3800	-0.1732	0.2221
7	6	-3.7700	-0.3700	-0.1707	-0.0441
7	7	-15.5400	11.9600	-0.2929	0.0343
8	0	1.5900	0.0000	-0.1656	0.0000
8	1	0.8600	1.2600	-0.3237	0.4875
8	2	-3.1200	0.9300	0.1716	0.2082
8	3	1.7600	-3.0900	-0.1426	0.6717
8	4	2.3700	0.1000	0.1277	0.7143
8	5	4.2100	3.1300	0.0394	-0.3742
8	6	-1.7800	10.0000	0.0532	-0.5415
8	7	-0.6400	-0.9900	-0.5157	0.3154
8	8	-2.9800	-18.3100	-0.3947	-0.6031

Table 6 Continued

n	m	g	h	$\dot{g}$	$\dot{h}$
9	0	-0.4500	0.0000	0.0000	0.0000
9	1	-2.9200	-1.1900	0.0000	0.0000
9	2	2.2200	1.6200	0.0000	0.0000
9	3	-3.9800	4.4900	0.0000	0.0000
9	4	4.7100	-3.2900	0.0000	0.0000
9	5	-3.1300	3.3900	0.0000	0.0000
9	6	-0.6000	4.4500	0.0000	0.0000
9	7	4.6600	-0.1100	0.0000	0.0000
9	8	-5.5300	-13.4100	0.0000	0.0000
9	9	20.5300	-4.9000	0.0000	0.0000
10	0	1.6200	0.0000	0.0000	0.0000
10	1	-0.1200	-0.2800	0.0000	0.0000
10	2	-2.3800	-0.4000	0.0000	0.0000
10	3	1.3200	3.8800	0.0000	0.0000
10	4	0.3600	1.3800	0.0000	0.0000
10	5	-3.3800	0.1600	0.0000	0.0000
10	6	0.0000	-2.5200	0.0000	0.0000
10	7	0.8200	0.4600	0.0000	0.0000
10	8	12.8400	-0.7600	0.0000	0.0000
10	9	8.1000	-2.5200	0.0000	0.0000
10	10	-2.0200	-7.7800	0.0000	0.0000

FIGURE CAPTIONS

Figure 1: Geographic distribution of POGS data selected from quiet days.

Figure 2: Correction in time applied to the POGS data.

Figure 3: Residual of the field magnitude of POGS data relative to the GSFC(8/91) spherical harmonic model. This model is derived from the POGS data itself.

Figure 4: Geomagnetic field spectrum. R_n is the total mean square contribution to the vector field by all harmonics of degree n.

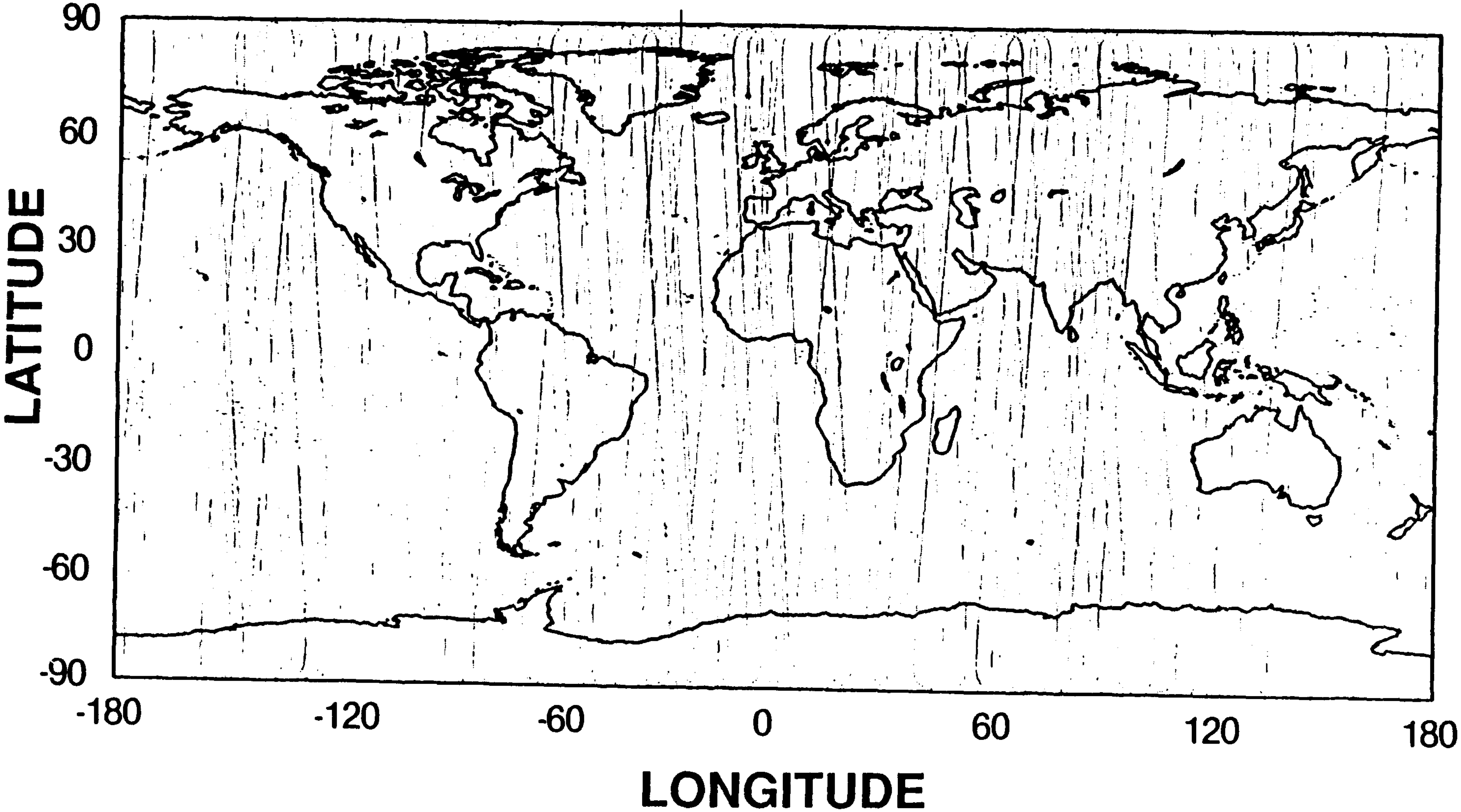
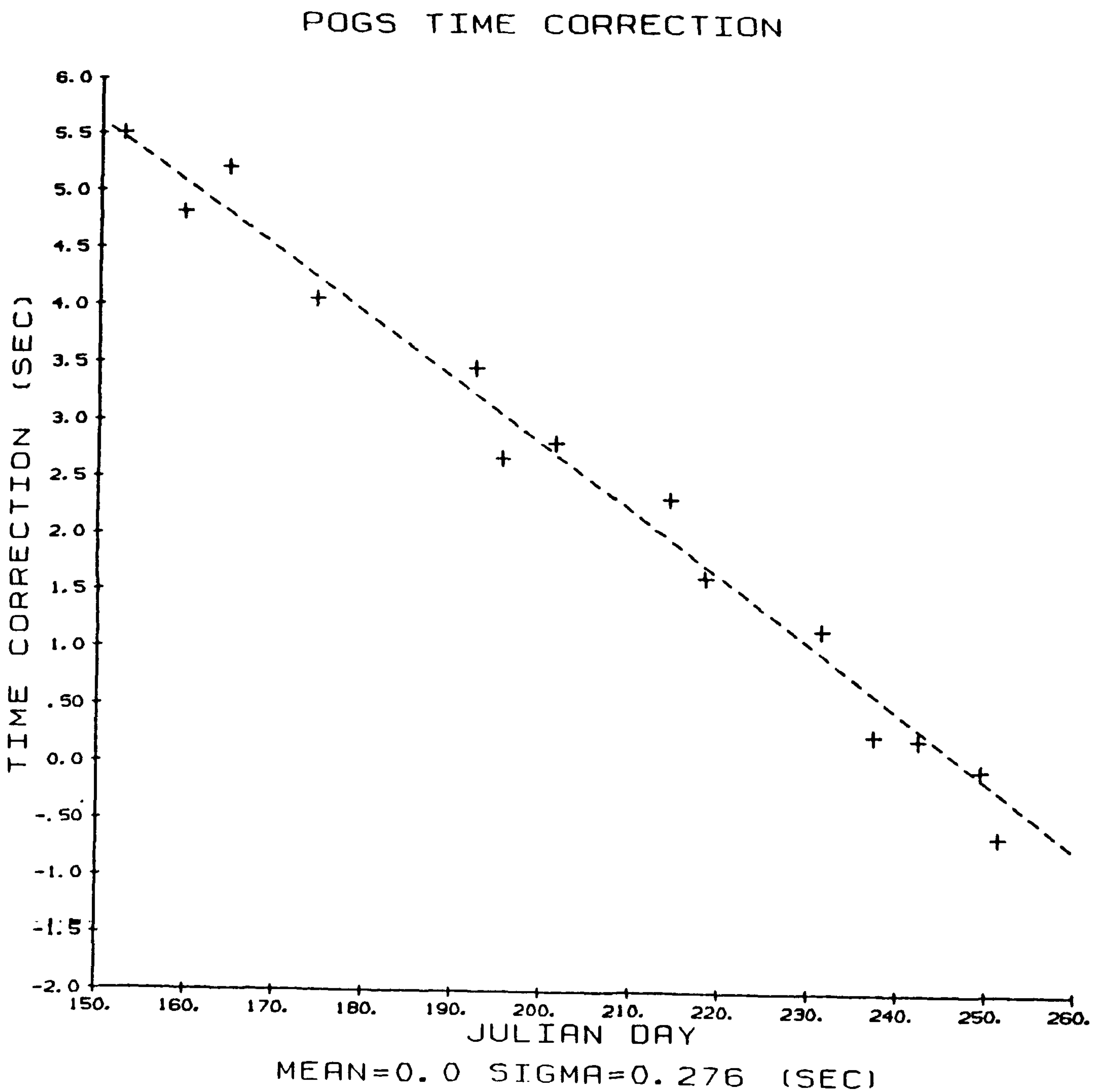


Figure 1.



POGS TIME CORRECTION
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.50
0.0
-.50
-1.0
-1.5
-2.0
TIME CORRECTION (SEC)
150.
160.
170.
180.
190.
200.
210.
220.
230.
240.
250.
260.
JULIAN DAY
MEAN=0.0 SIGMA=0.276 (SEC)

Figure 2.

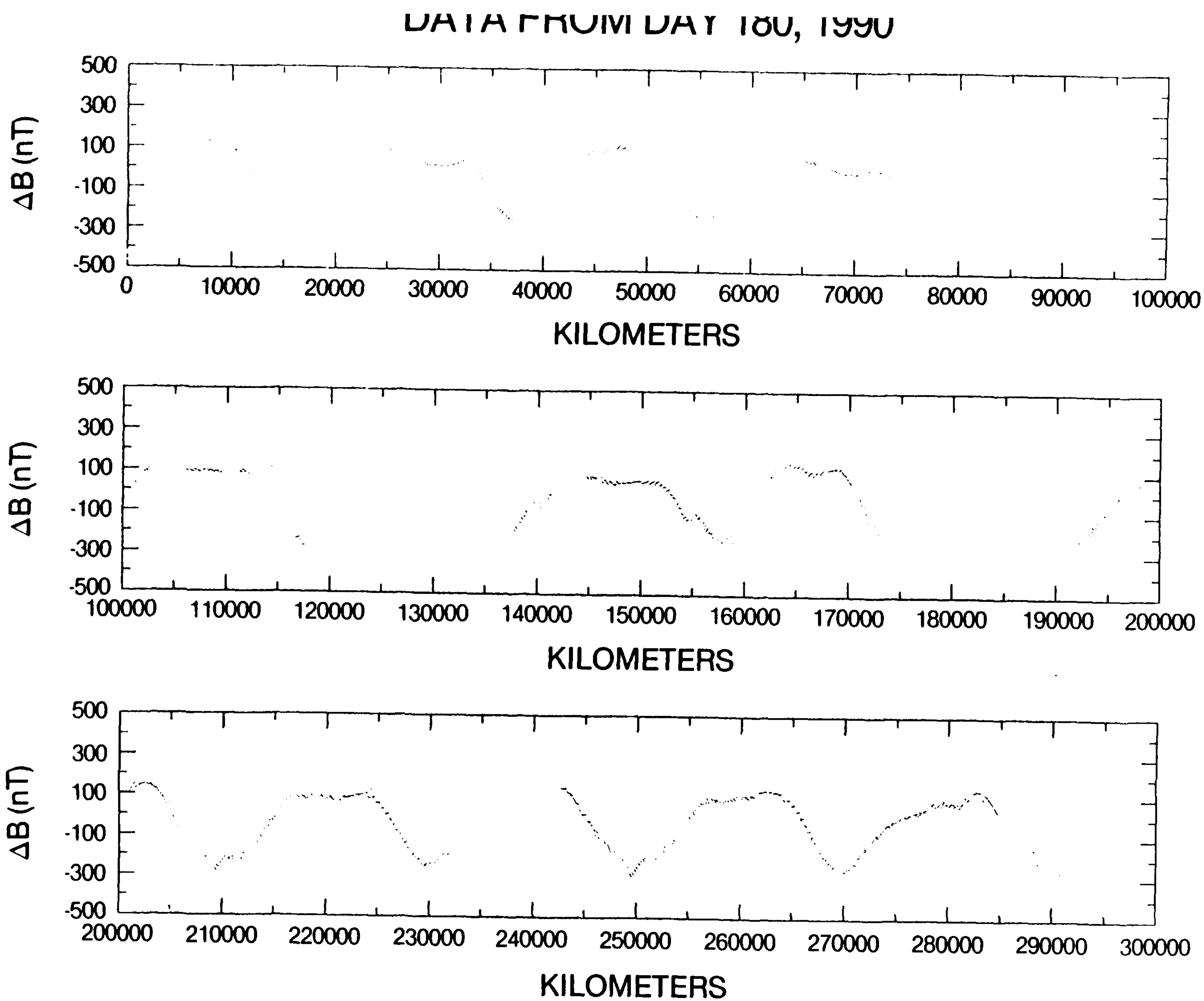

DATA FROM DAY 180, 1990
ΔB (nT)
500
300
100
-100
-300
-500
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
KILOMETERS
ΔB (nT)
500
300
100
-100
-300
-500
100000
110000
120000
130000
140000
150000
160000
170000
180000
190000
200000
KILOMETERS
ΔB (nT)
500
300
100
-100
-300
-500
200000
210000
220000
230000
240000
250000
260000
270000
280000
290000
300000
KILOMETERS

Figure 3.

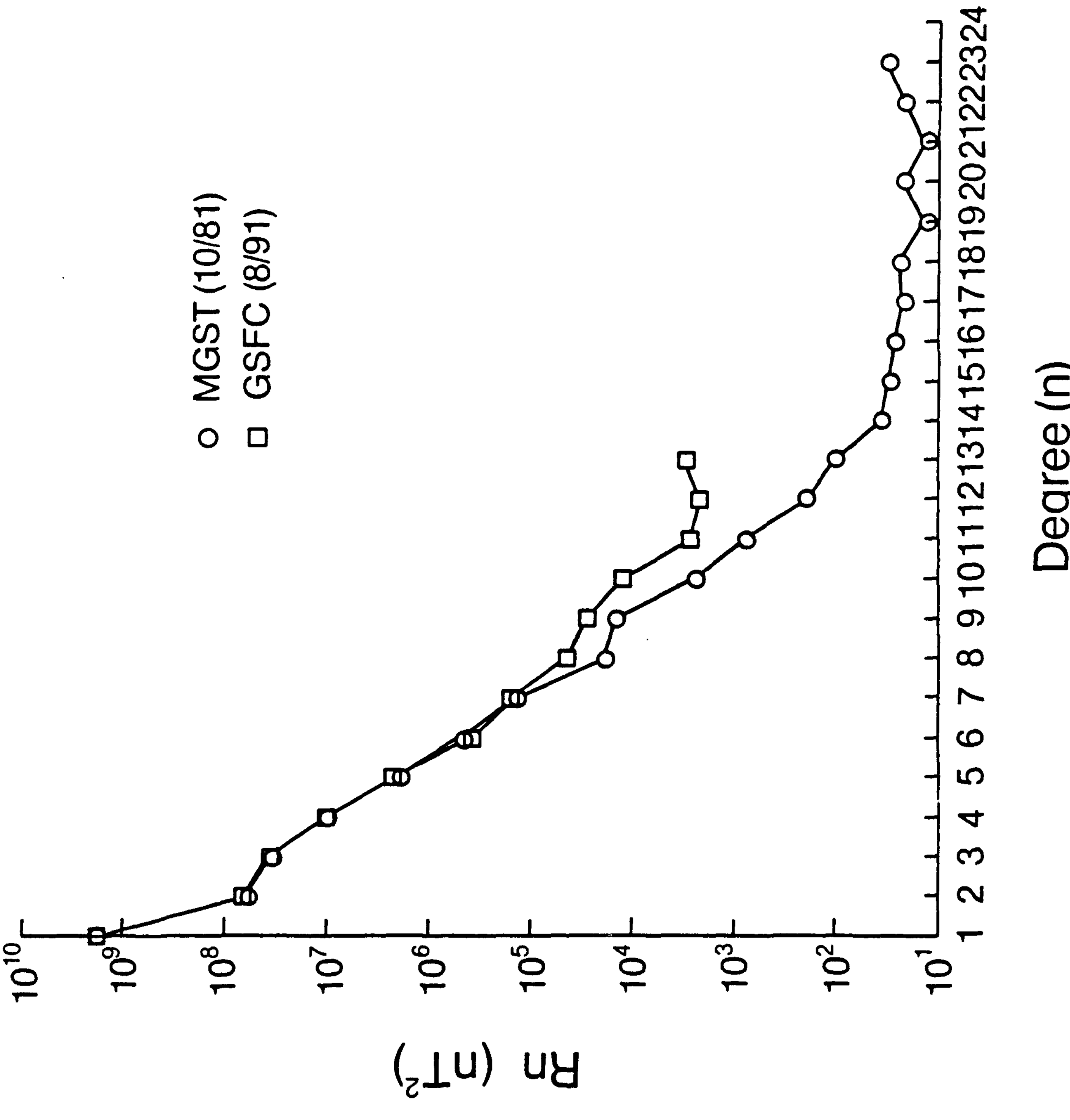

MGST (10/81)
GSFC (8/91)
Rn (nT²)
10¹⁰
10⁹
10⁸
10⁷
10⁶
10⁵
10⁴
10³
10²
10¹
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Degree (n)

Figure 4.